Design of a Novel Simulink Model for Surface Electromyographic (SEMG) Sensor Design for Prosthesis Control

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***Abstract*— This paper presents design, simulation and fabrication of a surface electromyographic (SEMG) sensor for control of prosthetic devices. EMG activity is mainly the generation of a bio-potential signal (electrical signals) due to muscle action. These signals picked from motor points of muscles are contaminated with various intrinsic/extrinsic noises, which must be removed through different filtering techniques in order to develop a sensor that has a high signal-to-noise ratio. Power spectral density (PSD) of any EMG signal plays a vital role to determine the signal strength. A novel Simulink model has been developed which mimics various elements of an active SEMG sensor. By using this model, low/high/notch filters are designed and optimized. The model is also used to simulate the effects of these filters on power spectral density (PSD) of the EMG signal. Simulation of double rectification and smoothing (envelopment) is also carried out. EMG signals recorded from the Tibialis anterior, monopolar needle, and fine wire isometric contraction were used in this simulation. Finally, on the basis of simulation results, instrumentation of surface EMG sensor is designed and fabricated. Performance/results of developed SEMG sensor are in accordance with the simulation results of the developed Simulink model.**

***Keywords*— Electromyographic (EMG), power spectral density (PSD), surface EMG (SEMG), Biomedical Simulink modeling.**

I. INTRODUCTION

Matlab Simulink is a powerful tool for simulation of any system and proven to be very beneficial for this research in designing of an active SEMG sensor due to its DSP toolbox. Various blocks used in this model have an array of parameters. By manipulating those concerned parameters, the effect on EMG spectrum against those parameters can be analyzed. Effect of different cutoff frequencies of filters (high/low/notch) on power spectral density (PSD) and FFT spectrum of EMG signal can be observed. Electromyographic (EMG) activity is mainly the generation of biopotential signal due to muscle action. These signals are contaminated with various noises such as ambient noise, motion artifacts and inherent instability of signal [1, 5]. These noises may be eliminated through different design/filtering techniques such as usage of an active sensor coupled with high pass/low pass/notch filter. The strength of these signals is very weak and normally amplitude of these signals lies in between 1-10 mV [1]. Generally, the frequency range of these signals is from 0-500 Hz [1] and most dominant is in between 50-150 Hz [1], where the signal amplitude is very significant [1]. Ambient noise generates from the 50 Hz radiation from power sources [1, 8]. The amplitude of ambient noise signal may be enhanced three times than the EMG signal whereas frequency range of motion artifacts/ inherent instability of EMG signal lies in between 0-20 Hz [1, 5]. These two noises can be eliminated with the help of proper high and notch filters in designing of the sensor. Nature of the amplitude of the EMG signal is quasi-random. Firing rate of motor units is quasi-random in the frequency range of 0-20 Hz and due to this effect, frequency components are unstable in this region and causes unwanted noise [1]. There are total six stages involved from acquiring EMG signal from muscle till the removal of noises. These are Instrumentation Amplifier, High pass filter, low pass filter, notch filter, double rectification and envelopment. A novel Simulink model is developed to mimics various filters of an active SEMG sensor as highlighted in Fig. 1-5, used in signal conditioning of raw EMG signal. On the bases of satisfactory results of simulink model, these filters are incorporated in fabrication of active SEMG sensor.

II. METHOD

A. Data Acquisition

A Matlab Simulink model is developed to design an active SEMG sensor. It is used to simulate the effect of cut-off frequencies of different low/high/notch filter on PSD of real single activity source of EMG signal. Real EMG signal is acquired from McGill KC, Lateva ZC, Johanson ME. Validation of a computer-aided EMG decomposition method. Proc IEEE Eng Med Biol Soc Conf, 4744-4747, 2004. [The data are available as dataset R002 at http://www.emglab.net].

It is a monopolar needle and fine wire isometric contraction. Mcgill KC, VA RR&D Ctr, Palo Alto, US. Transformation of this dataset, in the form of an array of data in Matlab, is done with the help of emglab1.03 software and store this data in Matlab workspace as a variable.

B. Transfer Function of Discrete Filters

To design SEMG sensor for prosthesis control, most important step is effective signal processing of raw SEMG signal. Our main focus is to develop SEMG sensor, so we require a suitable RC values for different filters involved in signal conditioning. By using those RC values, transfer function of high/low/notch filters in S-domain is evolved as mentioned in (1), (3) and (5) respectively. As acquired data of real EMG signal for simulation purpose is in discrete form so we also require a transformation of these transfer function from S to Z-domain. Transfer function of Sallen - Key high pass (f_c=20Hz) second order active filter in S and Z-domain is:-

$$H(s)= [s^2]/[\ s^2 + 181.81\ s + 16233.766] \tag{1}$$

$$H(z)=[z^2 - 2\ z + 0.999] / [\ z^2 - 1.982z + 0.9823] \tag{2}$$

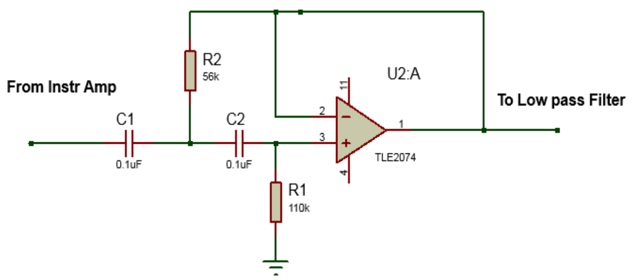

Fig. 1. High pass filter at the slope rate of -12dB/octave.

Transfer function of low pass (f_c=490Hz) second order active filter in S and Z-domain is:-

$$H(s)= (9391435) / [s^2 +s(4132.23) +9391435] \tag{3}$$

$$H(z) = [0.04079\ z + 0.03554] / [z^2 - 1.585z +0.6615] \tag{4}$$

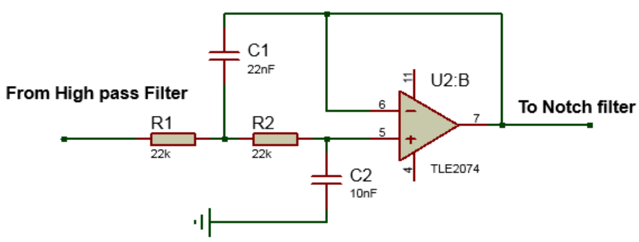

Fig. 2. Low pass filter at the slope rate of -12dB/octave.

Twin-T notch filter is used to eliminate power line noise source from EMG signal. Transfer function of twin-T Notch filter in S and Z-domain is:-

$$H(s)= [s^2+97900.85] / [s^2+1251.56s+97900.85] \tag{5}$$

$$H(z)= [z^2 -1.999z + 1] / [z^2 - 1.881z + 0.8824] \tag{6}$$

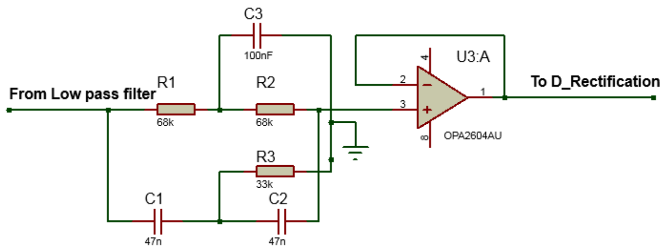

Fig. 3. Twin T notch filter used in sensor fabrication.

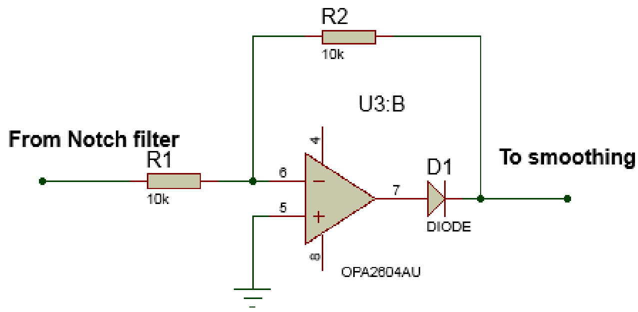

Fig. 4. Double rectification circuit used in sensor fabrication.

Transfer function of low pass filter (f_c=2.34Hz) for envelopment of signal in S and Z-domain is:-

$$H(s)= [14.7] / [s+14.7] \tag{7}$$

$$H(z)=[0.001469] / [z - 0.9985] \tag{8}$$

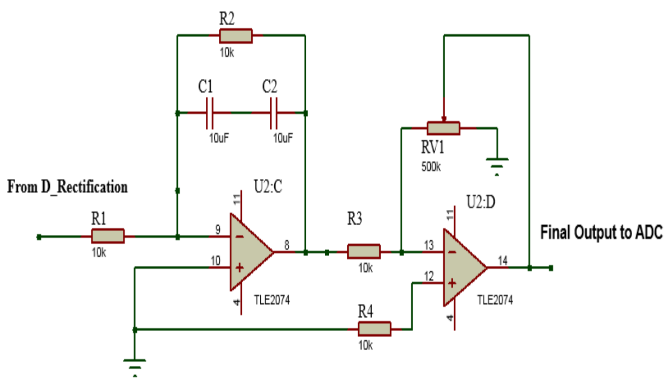

Fig. 5. Smoothing of EMG signal at 2.34 Hz.

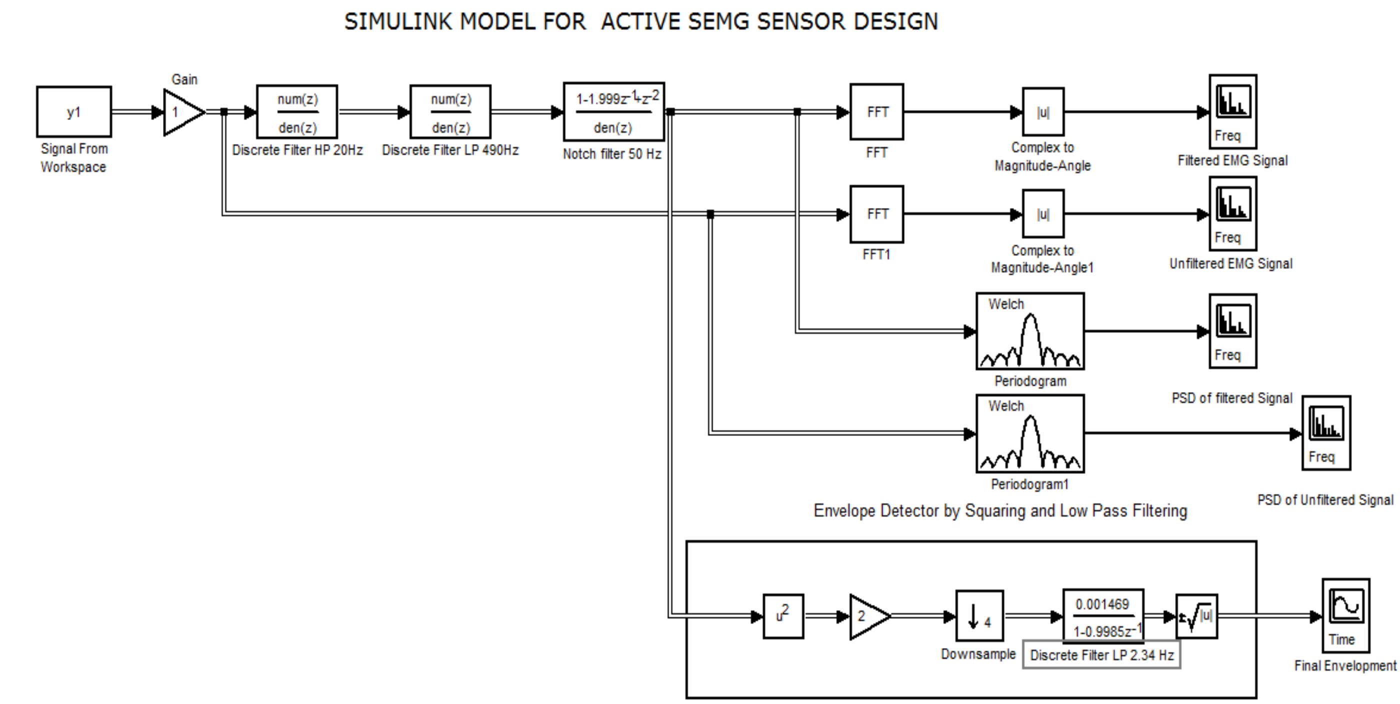

Fig. 6. Matlab Simulink model for designing SEMG sensor.

C. Development of Simulink Model

Real EMG signal is used in this model to simulate the effect of all 6xstages involved in designing of SEMG sensor. It acquires discrete data set from Matlab workspace and through Gain block processed it through 3x discrete filter blocks for high/low/notch filters respectively. Transfer functions for high/low/notch filters as mentioned in (2), (4) and (6) respectively are used in discrete transfer function blocks. As data is in discrete form, the fixed step discrete configuration is used in this simulation. Signal is firstly high pass filtered (f_c=20Hz) then processed through low pass filtered (f_c=490Hz) and lastly fed through a notch filter to eliminate f_c=50Hz power line noise. The amplitude of SEMG signal is random in nature [1]. Its amplitude swings rapidly between above and below zero volts. In digital signal processing, to remove the rapid fluctuation in the signal, generally the average of the random values is obtained. It is analogous to smoothing operation in analog but simply averaging of the random values of the signal might produce meaningless results. Thus, before averaging out the signal, rectification of the EMG signal is mandatory. Normally, the full-wave rectification is preferred so that all the energy of the signal could be retained. For double rectification and envelopment, “squaring and low pass filtering” technique is used. FFT block shifts the data from time domain to frequency domain and FFT spectrum is shown on Vectorscope. Periodogram block using Hanning window generates PSD of

III. RESULTS

Real raw EMG signal R00203 is utilized in this simulink model. If we analyze the spectral plot of EMG signal in Fig.7, it depicts that band width of raw signal is from 0-1.5K Hz containing intrinsic/extrinsic noises [2, 5].

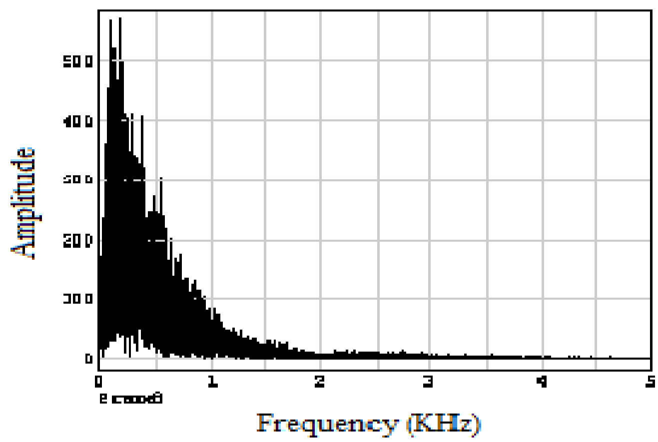

Fig. 7. FFT Spectrum of raw EMG signal (Amplitude Vs Frequency (KHz)) is acquired from the Simulink model. This spectrum shows that EMG signal contains both intrinsic/extrinsic noises.

Sampling rate of data set was 10K Hz and total 131072 discrete samples are used in this study.

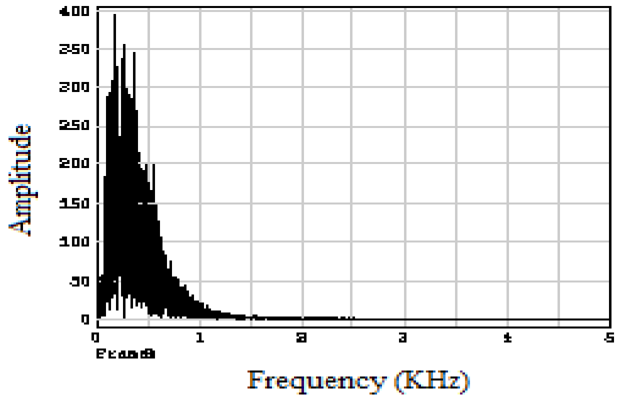

Fig. 8. Spectrum response of filtered EMG signal against 2[nd] order high pass filter (f_c=20Hz) and low pass filter (f_c=490Hz)

Similarly, effect of notch filter against 50 Hz frequency is highly evident in power spectral density (PSD) of EMG signal, as shown in Fig.9.

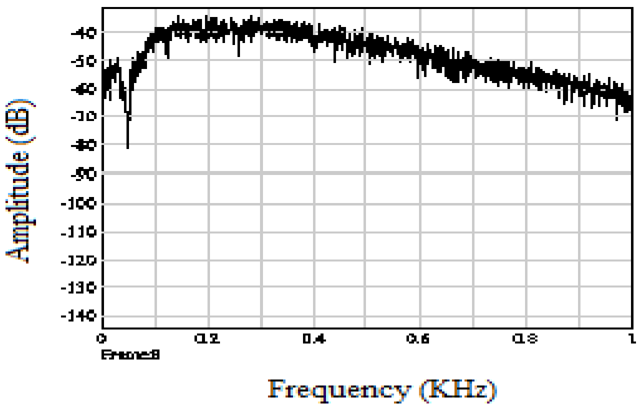

Fig. 9. PSD of filtered EMG signal is acquired from this simulink model by using Hanning window in Periodogram block.

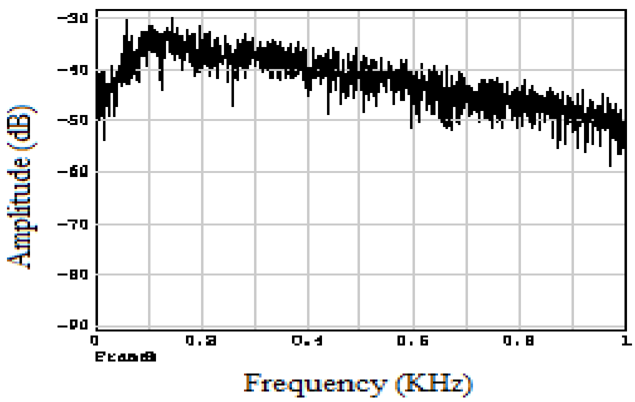

Fig. 10. PSD of unfiltered EMG signal is acquired from simulink model by using Hanning window in Periodogram block.

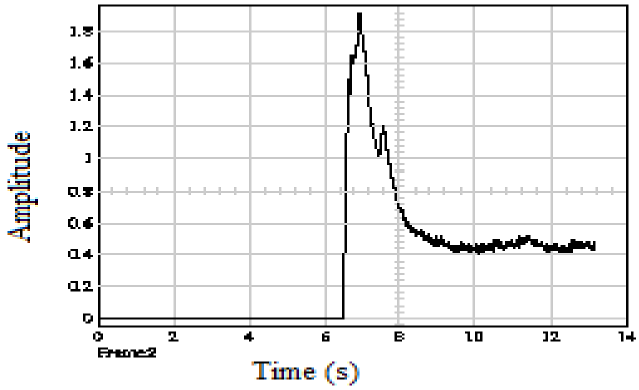

Fig. 11. Squaring and low pass filtering unit is used in this model to get smoothing of EMG signal.

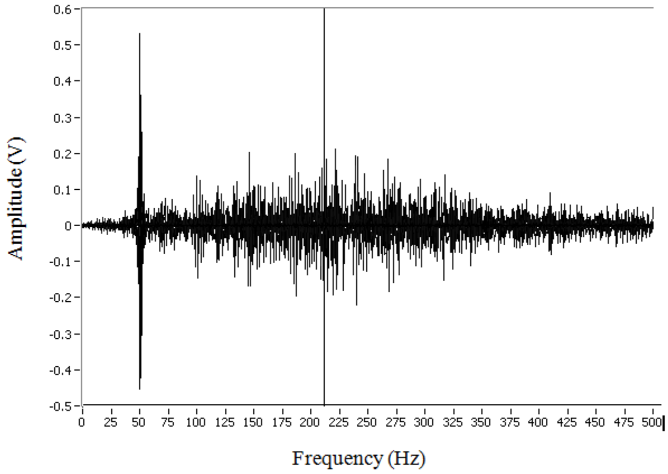

Fig. 12. FFT of Raw SEMG signal acquired from fabricated sensor.

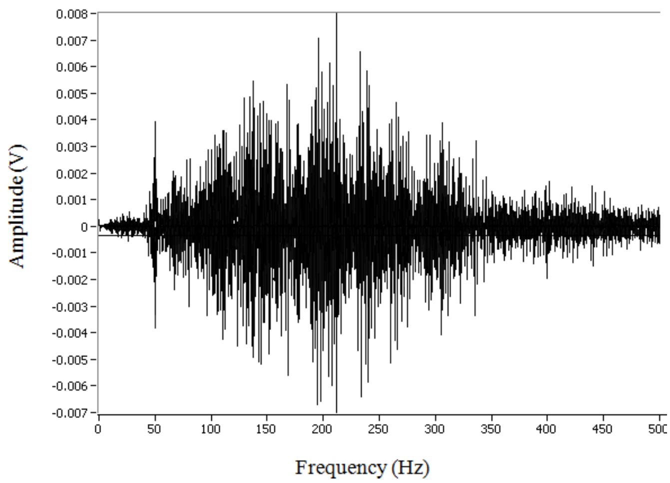

Fig. 13. FFT of filtered SEMG signal is acquired from fabricated sensor through Labview software. Filteration of raw SEMG signal is carried out through high, low and notch filters of fabricated SEMG sensor.

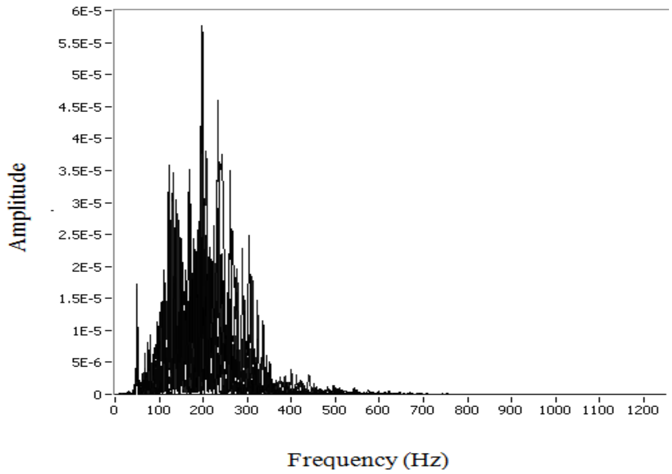

Fig. 14. PSD of SEMG signal is acquired from fabricated sensor through Labview software.

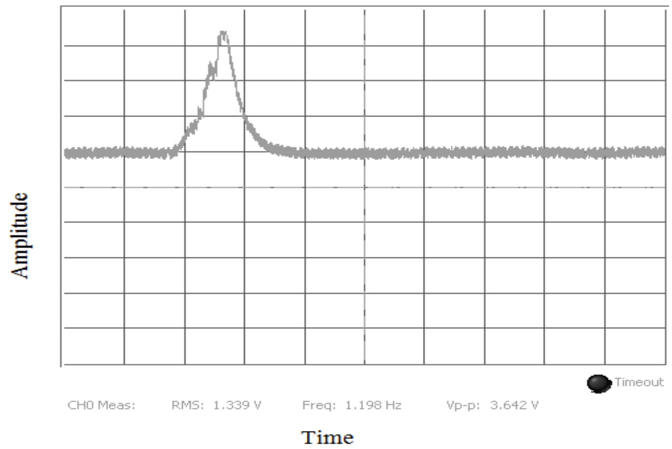

Fig. 15. Envelopment of SEMG signal acquired from fabricated sensor.

IV. DISCUSSION

An analog signal comprises of components at various frequencies. Highest frequency component present in signal dictates the bandwidth of the signal. As per Nyquist theorem, the sampling rate of the signal must be at least twice of the maximum frequency component present in signal otherwise aliasing will occur. In our study, we are more interested to simulate the effect of cut-off frequencies of different low/high/notch filter on FFT and PSD of real single activity source of EMG signal. So frame base operation is chosen in this model. As sampling rate of selected discrete EMG signal R00203 is 10K Hz. So we choose 16384 samples/frame, which also fulfill the criteria (2^N samples) to get FFT of the signal. Normally bandwidth of EMG signal is 20-500Hz [7]. So to get this bandwidth, second order high pass filter (f_c=20Hz) is used, which filtered motion artifacts and baseline noises. For higher frequency components more than 500 Hz, a second order low pass filter (f_c=490Hz) is used. If we analyze Fig. 7 to Fig. 9, it is clearly evident that raw EMG signal is effectively processed in the range of 20-500 Hz at the slope rate of -12dB/octave [3]. Furthermore to remove power line noises, notch filtering due to Twin-T notch filter is very obvious in Fig. 9. Finally, the envelopment of EMG signal can be witnessed in Fig. 10. As squaring and low pass filtering technique is used in this model for envelopment. Squaring block squares the EMG signal and demodulates the input by using input as its own carrier wave. Resultantly half of the energy of EMG signal is pushed up to the higher frequency and rest is shifted down towards DC. As we keep only lower half of the signal energy, thus scale block (scale=2) will match the final energy of the signal to its original. Down sample block will decimate the signal by factor 'K' and resultantly signal rate will be reduced from F_s to F_s/K [6]. In this model, we have selected K=4, so this block will keep 4^{th} number sample each time and discard 3xsamples each time so resultantly left with 32768 sample points[6]. As frame based operation is being performed in this model, so frame based option along with multirate processing option is selected in this block. So the size of the frame is 16384 samples/frame, which is also multiple of K factor (K=4) [6]. Low pass discrete filter is used to get envelop of EMG signal at 2.34 Hz [4]. Square root block reverses the scaling distortion due to squaring of the signal.

As the main focus of this study, was to design an active SEMG sensor with the help of Simulink model. So discrete transfer function blocks are used instead of digital filters. Best part of this model is that one can visualize the performance of EMG sensor from amplification till conditioning of EMG signal by using online available real EMG data before fabrication of sensor. On successful results of these filter blocks, same RC values are incorporated in hardware circuitry of EMG sensor. Bipolar power supply ±5V is used in circuitry. AD620 Instrumentation amplifier IC is used for differential amplification of SEMG signal, acquired from skeleton muscles through silver electrodes directly connected to AD620 IC as shown in Fig. 16. Other circuitry for signal conditioning is incorporated in sensor fabrication as shown in Fig. 1 to Fig. 5. Labview software is used to acquire FFT and PSD of SEMG signal. If we analyze the FFT of filtered signal as highlighted in Fig. 13, fabricated sensor has effectively filtered noise component below 20 Hz and over 490 Hz. Furthermore notch filter has removed power line noise components as was evident in Fig. 12. If we compare the results of FFT and PSD of Simulink model as in Fig. 8, 9 and fabricated sensor as in Fig. 13, 14; both have effectively conditioned EMG signal between 20-500Hz. Power line noises have also been successfully eliminated.

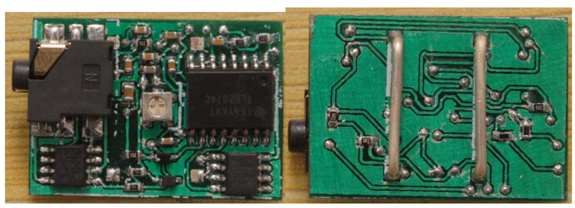

Fig. 16. Active SEMG sensor (Top and bottom side) is developed on the basis of a successful simulation of raw EMG signal.

V. CONCLUSION

Simulink model developed in this work has proven to be a novel and useful approach towards designing of instrumentation of surface EMG sensor. Since the model mimics various elements of the active SEMG sensor, researchers can test response of sensor by giving any raw EMG signal as the input. It is also beneficial for design, analysis and optimization of analogue filters (high/low/notch), which are used in signal conditioning of raw signal acquired from SEMG sensor. Results of the Simulink model and developed SEMG sensor have shown close resemblance, therefore, the model will be used for further research in domain of electromyogram.

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